An approach to the simulation of an industrial enterprise for the purpose of evaluating alternative decision algorithms is illustrated.

As an example, simulation of an integrated steel mill is discussed in sufficient detail to display programming techniques.

A general purpose digital simulator and examples of its application

Part IV — Simulation of an integrated steel mill

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As discussed elsewhere,[1] simulation is useful in studying the control mechanism of a manufacturing enterprise. The simulation involves a model representing both the information and physical systems and permits examination of alternative decision algorithms.

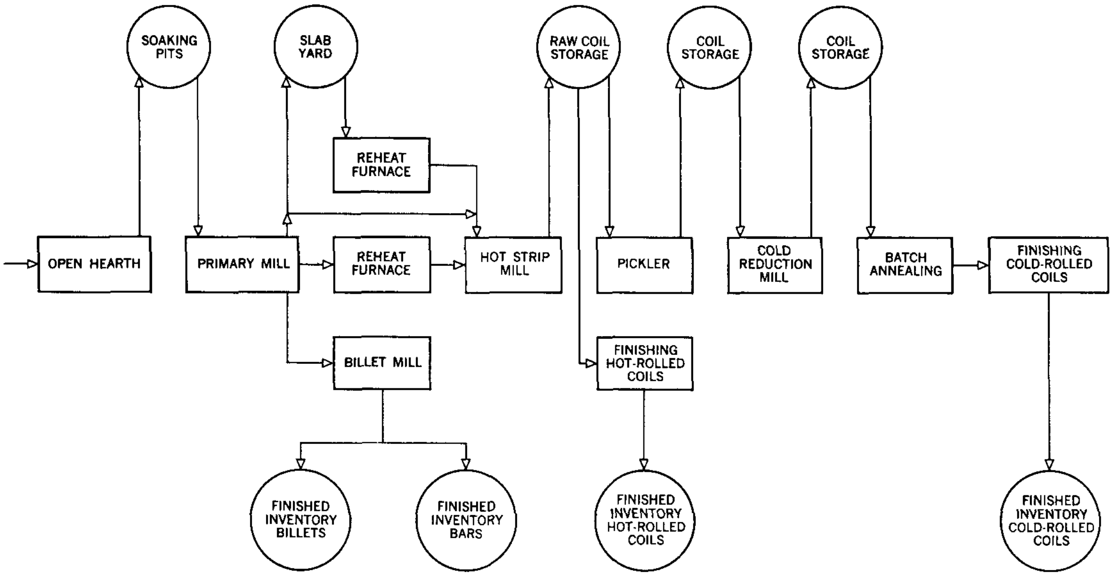
The purpose of this article is to give a brief indication of how such simulations may be effected by means of the simulator. Simulation of an integrated steel mill is described in sufficient detail to display programming techniques. Although the structure of the model is hypothetical, it is based on activities observed in a number of mills and representative of a wide class of integrated mills within the steel industry. A schematic diagram of a steel mill is shown in Figure 1.

physical system

To control the scale of the model, production is limited to four basic products—billets, bars, hot-rolled sheet, and cold-rolled sheet—although, within each major product, a wide variation of individual orders may be accommodated. The scale selected is of sufficient detail to permit useful evaluation of alternative decision procedures applied to control of the mill; at the same time, the structure has been simplified sufficiently to hold the model to a manageable size.

In the model, the operating units are characterized by a capacity representing the maximum tonnage that may be processed through the particular unit in a day, and by an average

Figure 1 Schematic diagram of a steel mill



throughput rate which may be a function of the characteristics of the material being processed and of the particular operating unit. Manpower, rather than being explicitly represented, is associated with the status of the operating unit. The steel is characterized by grade and form. The movement of steel through the mill involves activities other than the actual processing of steel, such as material movement and temporary storage. Certain physical constraints are recognized by the model. For example, normal operating procedures make it impractical for two open-hearth furnaces to pour simultaneously.

information system

The information processing system is concerned exclusively with the requirements of controlling the physical system of the mill. Central to the control system is the mill order, which is a customer's request for a particular product. Mill orders flow through the system in parallel with the physical flow of steel through the mill. Files of orders are maintained at each storage area throughout the mill. Orders move from one file to the next when all the material associated with the order has been processed through a unit to the subsequent storage area. Selection of material for movement out of the storage areas is based on information contained in the order file.

The model explicitly recognizes certain functions performed by the information processing system:

- *Sensing of information* — the input of data either manually or automatically into the information processing system.
- *Information transmission* — including the delays associated with such transmission.

- *Decision making* — the ultimate capability for controlling the operations of the mill depends upon the quality of these decisions. The information processing system is concerned primarily with servicing the various decision points.
- *Commands* — produced by the decision making activities and implemented by modifications within the physical system.

decision structure

The decision structure incorporated in the model is adequate to maintain the performance of the mill but not to optimize performance. Although simple, the structure is sufficiently elaborate to permit the desired evaluation of alternative decision rules with respect to improved control. The model is arranged so that decision rule modules may be replaced or expanded with only minor modification of the accompanying computer program.

Upon receipt of a customer order, a number of decisions must be made before the order can be processed. These decisions determine:

- The amount of steel to be produced for this order at the open hearth.
- The scheduling of the order through the mill.

The first decision takes into account expected scrap rates. The second decision assigns a promise date which establishes priority for processing the order as it moves through the mill.

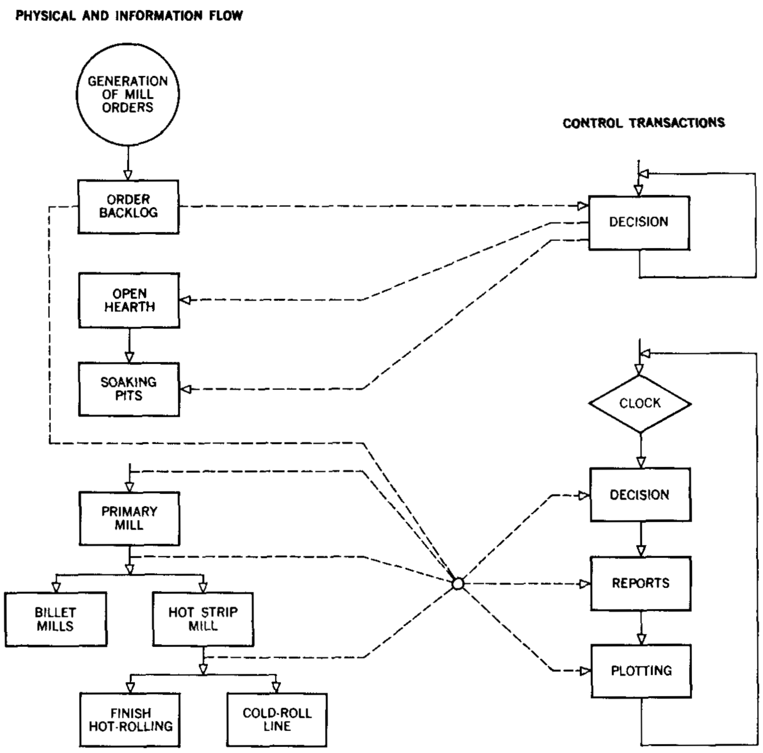
Each operating unit decides the sequence in which it processes material. These decisions have a major impact on the over-all performance measured in terms of meeting customer commitments. Although the decisions differ somewhat from unit to unit, they contain many common elements. At the open hearth, for example, the decision consists of selecting the grade of material for the next heat to be run. The mill manufactures six grades of steel, and sequencing must be consistent with the order backlog in each of the six categories. The grade of material selected is associated with that grade backlog which contains the order of earliest promise date. As many orders as possible are selected to complete the heat, up to the capacity of the furnace.

An additional important decision area is that of matching the effective capacity of the mill to the processing loads imposed by the current mix of customer orders. As in the case of an actual mill, this is accomplished by generating a weekly operating schedule. The schedule is based on the estimated number of 8-hour turns or shifts that each processing unit must be operated during the coming week in order to process the work load ahead of each unit. The operating schedule is then followed by the model during each simulated week, with processing units being activated or shut down as called for by the schedule.

accounting structure

Comprehensive data, readily available from the model, describe virtually any aspect of the events and activities taking place within the model during a simulation run. Thus, basic information covering the movement of ingots, slabs, and coils

Figure 2 Program structure



into and out of the operating units and storage areas, as well as the resulting rates and levels, may be obtained in the form of a time series of values, with the reporting interval being selected by a program option. In addition, summary statistics may be obtained for the simulation run as a whole, giving average utilization or occupancy of units or stores as well as statistical distributions of such values as transit times through the mill. In addition to the physical output data, the model provides a complete financial accounting structure which closely parallels the cost accounting system used in most mills. Three conventional operating and financial reports are produced: the weekly operating report, the weekly manufacturing expense and cost performance report, and the monthly financial statements.

computer program

The simulation model was programmed in GPSS II. Extensive subroutines were written in FAP, access being provided by the HELP block. A modification to the simulator permitting overlap of the input/output and execute sections allowed the construction of a somewhat larger model.

Figure 2 is a schematic of the over-all program. It includes the physical and information systems as well as the "decision" transaction loops which, by sensing the information flow, control the physical processes. For example, the availability of an open-hearth furnace triggers a transaction which activates a priority decision rule which, in turn, introduces a new heat into the open hearth. Similarly, other decisions are triggered by the movement of transactions in the physical and order-flow systems. Certain decision rules, such as those involved in the generation of the operating schedule, are activated on a calendar basis (once per turn, once per week, etc.). These decisions, together with such other periodic routines as report generation, are triggered by a control transaction gated on the simulator clock.

Figure 3 depicts a section of the GPSS II block diagram for the physical and information systems. A transaction in the model may either represent a mill order or units of material, depending upon whether it is a member of the inventory queue (order file) or of the work queue (units scheduled for processing during the current turn).

When the control transaction selects an order to be processed next, this order is decomposed into units of material. These units go through the process and are assembled again into orders before entering the next order file.

Figure 4 shows the computation of the operating schedule for one processing unit. A segment of the GPSS II block diagram appears on the left side of the figure, and its relation to the over-all program is shown in conventional symbols. At the beginning of the week, the control transaction picks up the total tonnage in an order file, determines the number of turns necessary to process it, and then selects the turn numbers from an "equally probable" distribution function. These numbers are stored in savex locations.

Figure 3 Flow of orders and material

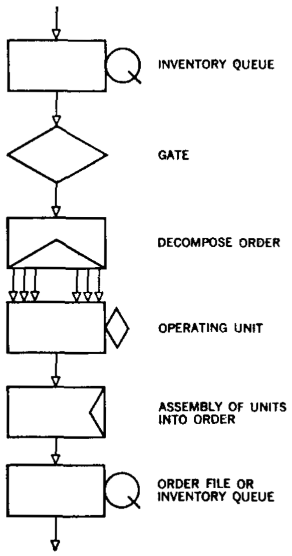


Figure 4 Operating schedule

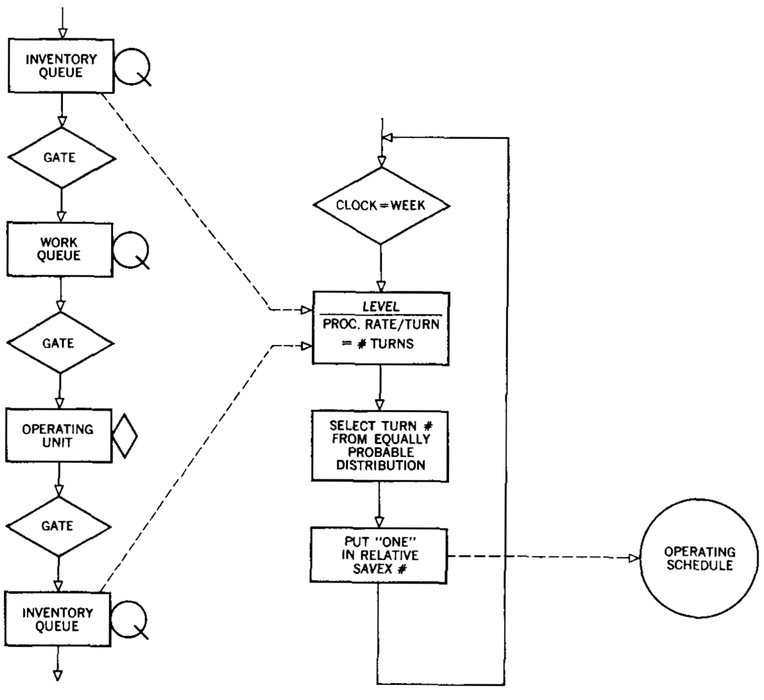


Figure 5 Sequencing

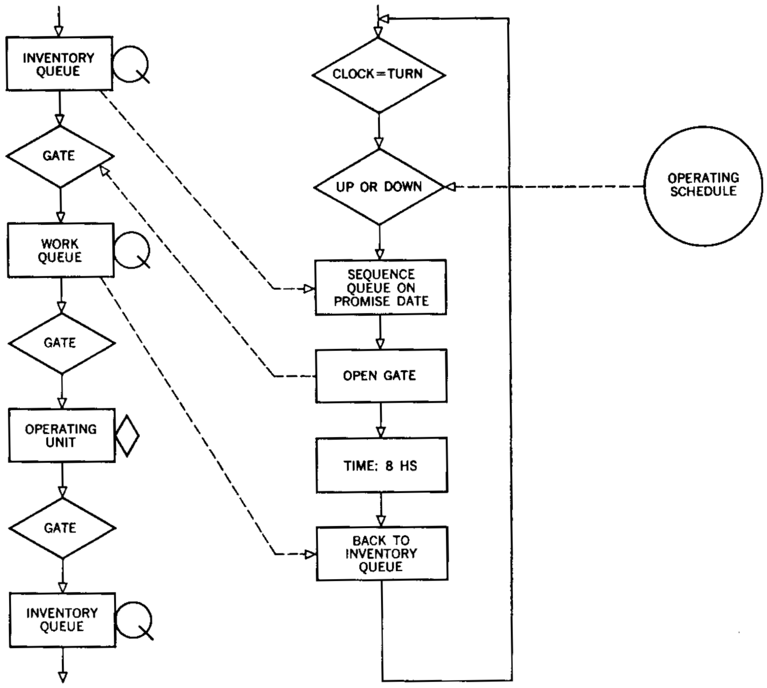


Figure 5, again with the GPSS II segment on the left, illustrates the implementation of the sequencing decisions. The control transaction checks the operating schedule to determine the status of a processing unit, and then goes into a HELP block where a FAP routine is executed, causing the sorting of the transactions in the order file. This sort routine physically moves the "order" transactions in the current events chain in accordance with the value of a transaction parameter.

Figure 6 Report generation

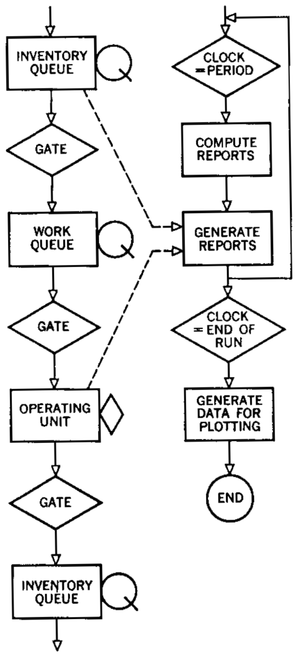


Figure 6 shows the computation and generation of the accounting and performance reports which are also accomplished with HELP blocks. Just before the completion of the run, all the data accumulated in 42 GPSS II tables are written on tape, which is then used as an input to a computer program that drives a digital plotter. The program is written so that nearly all data can be obtained in graphical form.

The model has the standard dimensions of the GPSS II deck, with the exception that it can hold a maximum of 1500 transactions. The capabilities of the HELP block are used extensively throughout the model. The simulation time unit is 1/100 of an hour; this small time increment is necessary for realistically describing the different physical processes. The running time (on an IBM 7090) is approximately six minutes per simulated week.

CITED REFERENCE

1. D. F. Boyd and H. S. Krasnow, "Economic Evaluation of Management Information Systems," *IBM Systems Journal* **2**, 2 (1963).